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THE ASIAN SEMICONDUCTOR INDUSTRY AND IT'S POTENTIAL IMPACTS TO U.S. NATIONAL SECURITY

ELECTRONICS INDUSTRY STUDY

COL CHARLES HOWE, USAF

MARK S. SPILLMAN, LT COL/O-5
SEMINAR 6

LT COL SEAN HERR, PRIMARY FACULTY ADVISOR

The Industrial College of the Armed Forces
National Defense University
Fort McNair, Washington, D.C. 20319-50

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Although the semiconductor industry began in the United States and many of its top innovations still come from this country, the Asian semiconductor industry is rapidly becoming a dominant force in the global marketplace. Today, the shift of numerous semiconductor activities to Asia is threatening a trusted manufacturing base for U.S. defense needs, increasing the likelihood of key U.S. military technologies transferring to potential adversaries, and weakening the economic strength of the nation in industries vital to technological growth. To protect U.S. national security interests, policymakers need to understand where the Asian semiconductor industry is headed, the implications changes may have on U.S. security, and what protective measures can be taken via policy. This paper begins with some background information on the semiconductor industry as whole, and the Asian semiconductor industry in particular. It then explores the outlook for the Asian semiconductor industry and its potential impacts on U.S. national security. Finally, it concludes with some recommended U.S. policy actions.

Semiconductor Industry Basics

The semiconductor industry began after key innovations such as Texas Instruments' invention of the integrated circuit (IC) in 1958 (Standard & Poor's [S&P], 2006, p. 21). Today, 86% of all products made in the industry are ICs (Datamonitor, 2006, p.10). IC development involves four major activities in a value chain: design, fabrication, packaging and test (Howe, 2006; Brown, 2005, p. 2). The design of circuit diagrams is skill dependent and relies on sophisticated electronic design automation (EDA) software (Brown, 2005, p. 2). During fabrication, the designs are "etched" onto silicon wafers layer-by-layer using masks, or reticules, and a process known as photolithography (Mathews, 2000, p. 37). This process is capital intensive with state-of-the-art, 300mm wafer fabrication plants, or "fabs," costing roughly $3 billion (B) (Howell, 2005, p. 2). Assembly and test involves cutting wafers into "chips" of completed ICs, packaging them into substrates and validating performance. These final steps require much smaller capital investments and less skilled labor (Brown, 2005, p. 3).

Historical Background on the Asian Semiconductor Industry

The Asian semiconductor industry began in the 1960s with small pockets of foreign investment, but quickly grew as countries nurtured their own industries. Japan was the first to establish a significant semiconductor industry in the 1970s (Nakayama, 1999, p. 47). In 1979, Fijitsu surprised the world when it became the first to mass produce 64 kilobyte memory chips (Mathews, 2000, p. 42). By the mid-1980s, Japan had cornered much of the memory chip market and surpassed the U.S. in semiconductor production (Mathews, 2000, p. 30). This rapid growth sparked a trade war with the U.S. which was resolved with a 1986 trade agreement (Mathews, 2000, p. 30). In the late 1980s, Korean firms began to compete globally on memory chips, with Samsung earning a sales profit in 1987 (Pecht, 1997, p. 10; Mathews, 2000, p. 30). Taiwanese firms, led by Taiwan Semiconductor Manufacturing Corporation (TSMC), the world's first dedicated foundry (or fab for hire), became competitive in the 1990s (Lee, 1997, p. 41). Singapore, Malaysia and China have since developed significant chip industries (Beane, 1997, p. 9; Pecht, 2007, p. 97).

Two major factors which contributed to the rapid growth of the Asian semiconductor industry were technology transfer via offshoring and public policy (Mathews, 2000, p. 31). The first U.S. offshore investment was made by Fairchild Semiconductor in Hong Kong in 1961 (Brown, 2005, p. 5). By the mid 1980's Japanese firms had executed over 40,000 foreign investment and partnering contracts, providing critical technology transfer (Rezvani, 2006, p. 2). Chip assembly was the first value chain activity to move offshore in the 1960s, followed by fabrication in the 1970s and design in the 1980s (Brown, 2005, p. 4). In each case, outsourcing to

Asian firms typically followed offshoring activities within a decade (Brown, 2005, p. 4). After the 1986 trade war with Japan, U.S. semiconductor investments shifted to Korea and other areas spurring growth around the region (Mathews, 2000, p.30). Asian governments also played a significant role in the growth of the industry by funding research and development (R&D), building industrial parks and providing subsidies.

Current Conditions in the Asian Semiconductor Industry

Today, Asia dominates the world's semiconductor industry in many aspects. Of the $248B generated in the industry in 2006, Asia (including Japan) accounted for over 60% of all sales (S&P, 2006, p. 9). This region currently leads the semiconductor industry in every major area with 65% of all IC sales, 64% of all equipment sales and 76% of all material sales (SEMI, 2007). This region is also the fastest growing in the world, with a 12.8% compound annual growth rate (CAGR) in sales over the last five years (2002-2006) as compared to 8.5% and 4.2% for the United States and Europe, respectively (Datamonitor, 2006, p. 8). This growth appears to be well correlated with overall chip demand. In 2006, over 60% of all chips made were consumed by the electronics industry in this region (S&P, 2006, p. 9). The largest end use markets were personal computers (44%), consumer electronics (17%) and cell phones (17%), all of which are increasingly manufactured in Asia, especially China (S&P, 2006, p. 2).

Of the top ten semiconductor companies in terms of 2006 sales, half are from Asia (sales in parentheses): #2 Samsung ($19.7B), #5 Toshiba ($9.8B), #6 TSMC ($9.7B), #7 Hynix ($8.0B) and #8 Renesas ($7.9B) (McGrath, 2007, p. 3). Samsung, headquartered in Seoul, South Korea, is well known for its consumer electronics and computers (S&P, 2006, p. 11). It is currently the number one producer of three popular memory chips: dynamic and static random access memory (DRAM, SRAM) and NAND flash memory (S&P, 2006, p. 11). The Japanese firm Toshiba is headquartered in Tokyo. It is one of the world's largest diversified electronic manufacturers and the inventor of NAND (S&P, 2006, p. 12). Headquartered in Taiwan, TSMC is the largest chip foundry in the world (S&P, 2006, p. 13). Hynix is another Korean firm headquartered in Seoul which specializes in producing memory chips. Finally, Tokyo-based Renesas is jointly owned by Hitachi (55%) and Mitsubishi (45%) (S&P, 2006, p.12). It is currently the top producer of microcontrollers used in a variety of markets such as autos (S&P, 2006, p. 12).

Outlook for the Asian Semiconductor Industry

Growth in the Asian semiconductor industry is expected to decrease slightly over the next five years but remain relatively strong due to regional chip demand and favorable business environments. The CAGR of sales is predicted to be 10.9% for the region from 2006-2011 (Datamonitor, 2005, p. 8). Fab capacity will continue to expand rapidly, especially in China, to meet chip demand. This demand is expected to increase due to a growing Asian middle class and an expanding electronic manufacturing industry servicing the world. In China alone local IC supply, currently at 6.5% of demand, will only be able to meet 11% of demand by 2010 (SEMI, 2007). Asia currently has over forty 300mm wafer fabs with an additional forty more planned or under construction (SEMI, 2007). This is more than three times the number of similar investments in North America (SEMI, 2007). Government taxes are also driving growth in Asia. A new fab in Asia currently costs about $1B less to operate over a decade than in the United States primarily due to lower taxes (Lyne, 2006, p. 6; Morrison, 2005, p. 3).

One global industry trend which may spur additional growth in Asia is the rapidly rising costs of R&D. Moore's Law, which predicts the number of transistors on an IC will double every 18 months, may not hold true much longer (S&P, 2006, p. 22). As companies attempt to make smaller, more powerful and less expensive chips they are increasingly facing more daunting technical challenges and escalating R&D costs. The current scaling approach is expected to be ineffective by 2020, at which point a fundamentally new chip architecture may be required (S&P, 2006, p. 22). Experts believe there is at least a $15B gap between what industry can afford and what it needs to stay on Moore's Law (SEMI, 2007). Higher R&D costs may favor additional growth in Asia where there are larger government subsidies and lower overall operating costs. On the negative side, however, parts of Asia, especially China, still lag behind the United States and Europe in terms of intellectual property rights and quality university research (Normile, 2005, p. 4).

Another broad industry trend which will affect Asia is continuing specialization and outsourcing. Although Integrated Device Manufacturers, or companies that conduct all semiconductor value chain activities, still dominate, the number of dedicated foundries and design, or fabless, firms is on the rise (Howell, 2005, p. 2). The rising cost of fab construction and operation is a significant driver. Of the hundreds of firms in the semiconductor industry worldwide, only an estimated 20 have sufficient revenues to afford their own 300mm wafer fab (SEMI, 2007). The dedicated foundry business is expected to experience double-digit growth over the next few years centered around existing players (Jelinek, 2006, p. 2). Since the first 9 of the top 10 dedicated foundries are all in Asia, this will likely mean more growth for the region (IC Insights, 2006, p. 2). Companies are also increasingly offshoring and outsourcing design activities, especially to areas with abundant lower cost engineering talent such as India (Davis, 2006, p. 2).

Government Involvement in the Asian Semiconductor Industry

Asian governments continue to spur growth in the region's semiconductor industry through a variety of business incentives, including tax breaks and direct investment. U.S.

industry experts believe these government incentives account for about 90% of the operating cost differential between Asia and the United States (Gruener, 2005, p. 1). China, Singapore, Malaysia and Taiwan have all offered significant tax advantages to indigenous semiconductor firms. Taiwan-based firms, for example, pay no taxes year after year (Howell, 2005, p. 3). In recent years, in fact, TSMC's after-tax income has been higher than its pre-tax income due to credits (Howell, 2005, p.3). Direct investments in terms of government stock ownership, land and infrastructure have also been significant (Lyne, 2004, p. 2). Many nations, such as Taiwan and China, are creating their own "Silicon Valley" industrial parks to bring together industry, research universities and venture capitalists. China is also offering free land for 50 years (Murphy, 2002, p. 2).

Asian governments are also attempting to improve their semiconductor industries through increased R&D and education. In China, where R&D spending is growing faster than the overall economy, government agencies doubled R&D investments between 1997 and 2002 (Normile, 2005, p. 1; Sayer, 2006, p. 1). In 2006, China and Japan ranked second and third in total R&D investment, respectively, by spending roughly one-third of the United States' $338B (Sayer, 2006, p. 1). China, however, was able to employ two-thirds the number of researchers as the United States at this lower spending level (Sayer, 2006, p. 1). China and India are also challenging the United States in engineering education. In 2003, China passed the United States in engineering PhD graduation rates (Wadhwa, 2007, p. 13). In addition, about 60% of U.S. engineering PhD degrees are awarded to foreigners, the bulk of which are Indian and Chinese (Wadhwa, 2007, p. 13). The number of Chinese students returning home after education is currently 30% and rising (Wadhwa, 2007, p. 13).

Industry Implications to U.S. National Security

One concern the U.S. Department of Defense (DoD) has with the rising strength of the Asian semiconductor industry is the loss of IC manufacturing capability in the United States. Today, IBM, Intel and Micron are the only U.S. companies which operate 300mm fabs in America (Vacca, 2007). The U.S. DoD and intelligence agencies have stressed that the country can not rely on foreign producers such as China, Taiwan and Singapore to manufacture the advanced ICs needed for defense. Given the increasing dependence of the country's "network centric" military force on advanced ICs, the erosion of the indigenous manufacturing base is significant (Lieberman, 2003, p. 3). If trends continue, defense experts worry that the country may lose access to secure fabs, which currently take 1-2 years to build (Lorick, 2003, p. 1). To preserve some secure advanced chip making capability, the DoD and the National Security Agency signed a 10 year, $600 million dollar deal with IBM in 2004 to use its Vermont fab as a "trusted foundry" for defense needs (McCormack, 2004, p.1).

Another significant U.S. defense concern related to the Asian semiconductor industry is the increasing movement of IC design activities to this region, especially to potential adversaries. As of June 2005, 13 of the top 15 U.S. semiconductor companies in the U.S. have opened research centers in India, and 5 have done the same in China (Brown, 2005, p. 24). While China's IC design capabilities are still meager, the country's growing chip manufacturing base and its efforts to attract top engineering talent will likely lead to significant improvement. Since semiconductor designers tend to closely interact with manufacturers, many experts believe that design activities will continue to naturally migrate to China and other Asian nations over time. As IC design talent moves abroad, however, other nations may be able to develop more sophisticated military hardware. This trend could significantly reduce the technological superiority advantage the U.S. military currently holds over potential adversaries.

The shifting of high semiconductor value chain activities, such as design, to Asia may also have long term consequences on U.S. economic strength, which is critical to national security. The U.S. semiconductor industry currently employs approximately 232,000 people which is down from over 260,000 in 1998 (Semiconductor Industry Association [SIA], 2007). As value chain activities move offshore, this number may continue to fall. The economic impact of higher end value chain activities, such as design, moving offshore is even greater as this change results in the loss of high paying engineering jobs. The semiconductor industry is also a vital foundation to the broader electronics industry, one of the largest and fastest growing industries in the world. This industry, which had estimated sales of $1,504B in 2006, is expected to grow at 8.25% over the next three years, or nearly double the rate of the world Gross Domestic Product (SEMI, 2007; Central Intelligence Agency [CIA], 2007). If the United States loses its design lead in semiconductors, it may also lose market share in the overall electronics industry which could hurt its future economic strength in a technology driven world.

Recommended U.S. Government Policy Actions

One of the first semiconductor-related national security issues the U.S. Government needs to address is the loss of IC manufacturing capability to Asia. While the Trusted Foundry Program is a step in the right direction, it relies on the strength of only one company (IBM). The U.S. Government should explore expanding the Trusted Foundry Program, perhaps through cooperation with trusted coalition partners such as Britain, Canada and Australia. Policymakers also need to examine improving the business case for fabs in America by countering foreign income tax incentives and tax holidays, and raising the 20% annual depreciation rate on these facilities (McCormack, 2005, p. 3). Additionally, the U.S. government should sponsor research to improve IC manufacturing flexibility and test processes. Flexible manufacturing is needed to efficiently handle smaller DoD chip orders, while better test processes will ensure that defense chips obtained from foreign sources are free of malicious logic.

To retain semiconductor design preeminence, the U.S. government needs to find ways to maintain the top semiconductor industrial parks in the world, such as "Silicon Valley," and to grow and retain the top IC design talent in the world. U.S. policymakers should support semiconductor industrial parks with university research grants and industry tax incentives for R&D and modernization. To help grow top IC design talent, Congress should sponsor efforts to benchmark U.S. education in all grades against the top performing nations in the world, particularly in math and science, and fund programs to close any gaps. Policymakers should also revise visa requirements to make it easier for foreign-born students to stay in the United States after completing advanced technical degrees in the country's top universities. Congress is reviewing several innovation and competitiveness bills to address these issues, however, none have been passed into law (Gordon, 2007, p. 1).

The U.S. government should also continue to pursue long-term strategies to protect U.S. military technological advantages and the country's ability to compete in the electronics industry. Smart domestic and international export controls are needed which can keep advanced military-use semiconductor technologies from potential adversaries without interfering with non-military commercial trade. These controls must clearly delineate prohibited nations and export technologies, and keep pace with rapid technological advancements. Critics argue that many current restrictions, such as radiation hardening provisions in existing International Traffic in Arms Regulations, haven't kept pace with technology changes (SIA, 2007b). As a result, many commercial video games, cell phones and computers may soon be classified as prohibited munitions (SIA, 2007b). The U.S. government also needs to continue to work with other nations and the World Trade Organization to guard against discriminatory practices, such as China's value-added tax laws prior to April 2005, which charged 14% more to non-Chinese semiconductor firms (Manufacturing & Technology News, 2003, p. 1; Lyne, 2004, p. 6).

Summary

The Asian semiconductor industry began in the 1960s, largely due to U.S. offshoring activities. Since that time, Japan, followed by Korea, Taiwan, Singapore, Malaysia and China have all nurtured significant semiconductor businesses via public policy. Today, the Asian semiconductor industry accounts for 60% of all IC-related sales and is growing faster than any other region in the world. The increasing shift of semiconductor activities to Asia, however, is beginning to threaten U.S. defense supplies and technological advantages, and weaken the country's economic strength in technology-based industries. The U.S. government needs to enact policies to expand the Trusted Foundry Program, improve defense chip manufacturing and testing, and maintain the best industrial parks and IC designers in the world. Additional policies are needed to better protect key military technologies from export, enforce fair trade practices and enhance the business case for fabs in America. In the absence of such policies, the United States will likely see its technology leadership position in the world further erode, which will weaken its overall security.

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